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【List of the Annexed Documents】

【Document】 Specification One copy

【Document】 Drawing One copy

【Document】 Abstract One copy

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【Proof】 Requested

【Document】 SPECIFICATION

【Title of the Invention】 Semiconductor Light Receiving Element

【What is Claimed is】

【Claim 1】 A semiconductor light receiving element, wherein the light receiving element is a Schottky barrier type semiconductor light receiving element, said light receiving layer has a first conductivity type layer comprising a GaN group semiconductor as a light receiving layer, one surface of said light receiving layer as a light receiving surface comprises at least a Schottky electrode, and a total of boundary lines between areas of the light receiving surface covered with the Schottky electrode and exposed areas is longer than the length of the outer periphery of the light receiving surface.

【Claim 2】 The semiconductor light receiving element of claim 1, wherein the Schottky electrode has a wiring pattern formed by strip conductors in combination.

【Claim 3】 The semiconductor receiving element of claim 2, wherein the strip conductors have a width of 0.1 μm - 2000 μm.

【Claim 4】 The semiconductor light receiving element of claim 2, wherein the wiring pattern is a comblike pattern.

【Claim 5】 The semiconductor receiving element of claim 1, wherein the light receiving layer is an uppermost layer of a laminate comprising one or more layers comprising a first conductivity type GaN group semiconductor formed on a crystal substrate, which element comprising an ohmic electrode formed on a layer other than the light receiving layer.

【Claim 6】 The semiconductor light receiving element of claim 5, wherein the crystal substrate is made from a conductive material and the ohmic electrode is formed on the crystal substrate.

【Detailed Description of the Invention】

【Technical Field to which the Invention pertains】

The present invention relates to a technical field of a Schottky barrier type element from among semiconductor light receiving elements, particularly to an element using a GaN group material.

【Prior Art】

To cope with the increasing density of integrated circuits, a stepper (step-and-repeat photolithographic system with demagnification) for forming a fine circuit pattern therefore is required to be capable of drawing more finely at higher resolution. Therefore, the laser beam used for exposure has been changed to that having a shorter wavelength range, from blue light to ultraviolet light, and changing the light having a wavelength of 248 nm (KrF excimer laser device) currently in use to the light having a wavelength of 193 nm (ArF excimer laser device) has been contemplated.

During the exposure step by the above-mentioned stepper, a part of the laser beam is received by a light receiving element and changes in the output and the like are monitored. As the light receiving element, a photodiode (PD) is useful. PD includes those made from Si group semiconductor materials. When the laser beam has a powerful energy, like the above-mentioned light at 248 nm, an Si group PD shows dramatic degradation, thus necessitating frequent replacement for a new one.

However, PD includes those based on many light receiving principles, one being a Schottky barrier type PD. With regard to the Schottky barrier type PD, wherein ultraviolet light is the receiving target; the invention disclosed in JP-A-61-91977 can be mentioned. This PD has a constitution wherein an AlGaN layer is grown on a sapphire substrate via an AlN buffer layer, and on this AlGaN layer are formed a Schottky electrode (electrode connected to form a Schottky barrier) and an ohmic electrode.

The PD of the above-mentioned publication has a structure wherein, as shown in Fig. 4(b), a light L3 (light

receiving target) that enters from the substrate side reaches an area 10b right under a Schottky electrode 20 (a part of depletion layer spreading on the semiconductor side), where it is received. An ohmic electrode 30 is also formed on the upper surface 10a of a semiconductor layer 10. It is evident from the structure, wherein the Schottky electrode occupies a large area of the light receiving surface and the light can enter only from the substrate side, that this PD allows light to enter from the substrate side. Also, this publication clearly states, "When a photon enters a depletion region under the Schottky barrier through a transparent Al_2O_3 substrate, a pair of electron-holes is produced."

【Problems to be Solved by the Invention】

However, the PD of the above-mentioned publication has the following problems.

① Due to the constitution wherein the light to be received is passed through a thick AlGaN layer from a sapphire substrate, and led to the back of the Schottky electrode where it is received, the light to be received is absorbed by the AlGaN layer and the sensitivity becomes low. In particular, a shorter wavelength of the ultraviolet light to be received is associated with a greater energy of the light, and as it separates from the band gap of AlGaN, an absorption coefficient of the light in the AlGaN layer suddenly becomes greater, and the light may not be able to reach a depletion layer region, which is formed by a Schottky junction, or a vicinity thereof at all.

② For the above-mentioned reason ①, the wavelength range of a detectable light is limited to a narrow range near the band gap of AlGaN. That is, a sensible wavelength range is narrow.

An object of the present invention is to provide a Schottky barrier type semiconductor light receiving element having, besides the superior resistance also to a light having a wavelength in the ultraviolet range, much superior

sensitivity as compared to conventional ones, based on a new constitution.

【Means of Solving the Problems】

The semiconductor light receiving element of the present invention is characterized by the following.

(1) A semiconductor light receiving element, wherein the light receiving element is a Schottky barrier type semiconductor light receiving element, said light receiving layer has a first conductivity type layer comprising a GaN group semiconductor as a light receiving layer, one surface of said light receiving layer as a light receiving surface comprises at least a Schottky electrode, and a total of boundary lines between areas of the light receiving surface covered with the Schottky electrode and exposed areas is longer than the length of the outer periphery of the light receiving surface.

(2) The semiconductor light receiving element of (1) above, wherein the Schottky electrode has a wiring pattern formed by strip conductors in combination.

(3) The semiconductor receiving element of (2) above, wherein the strip conductors have a width of 0.1 μm - 2000 μm.

(4) The semiconductor light receiving element of (2) above, wherein the wiring pattern is a comblike pattern.

(5) The semiconductor light receiving element of (1) above, wherein the light receiving layer is an uppermost layer of a laminate comprising one or more layers comprising a first conductivity type GaN group semiconductor formed on a crystal substrate, which element comprising an ohmic electrode formed on a layer other than the light receiving layer.

(6) The semiconductor light receiving element of (5) above, wherein the crystal substrate is made from a conductive material and the ohmic electrode is formed on the crystal substrate.

The light receiving surface of the present invention refers to, of the both surfaces of the light receiving layer,

the entire surface where the light is received. The Schottky electrode is formed to partially cover this light receiving surface. In the following, the area of the light receiving surface, which is covered with the Schottky electrode, is to be referred to as an "electrode area" and the exposed area is to be referred to as an "exposure area" for explanation.

【Action】

The semiconductor light receiving element of the present invention (hereinafter a light receiving element) is a Schottky barrier type PD. Therefore, not only the Schottky electrode but the other corresponding electrode is formed to function as a light receiving element. This other electrode is preferably an ohmic electrode. The ohmic electrode is to be explained later. The mechanism itself of the photodetection using the Schottky barrier is the same as for a conventional Schottky barrier type PD. Briefly explaining an n-type light receiving layer, a backward bias voltage is applied between the both electrodes to facilitate the flow of electron from the light receiving layer to the Schottky electrode, and the flow of the electron generated in the light receiving layer by the light excitation is detected as a current.

The important characteristic of the present invention is taking note of the fact that a depletion layer 1b is larger than Schottky electrode 2 and covers a small area around the electrode, extending from under the electrode, as shown in Fig. 4(a), and utilization of the area. The light L1 can enter this small area (hereinafter an extending part of the depletion layer) of the depletion layer extending from around the electrode also from the upper surface side of the electrode. Even if completely under the Schottky electrode, light can enter the vicinity of the outer periphery of the electrode from an oblique angle, like light L2. In addition, the light that entered the semiconductor causes an interaction with the depletion layer under the electrode due

to the diffraction effect.

In the present invention, this extending part of the depletion layer and the area of the depletion layer near the part directly below the periphery of the electrode are secured as widely as possible, to positively utilize the area for detection of the received light. For this end, it is important that the boundary line between the electrode area and the exposure area be longer. According to the present invention, the Schottky electrode is made to have a complicated shape, so that the length of the boundary line can be longer than the total length of the outer periphery of the light receiving surface, thereby to detect the light irradiated from the upper surface side of the electrode.

In contrast, in a conventional Schottky barrier type light receiving element, as shown in the above-mentioned publication and Fig. 4(b), the light to be received L3 enters from the substrate side and is received at the central part of the depletion layer 10b formed on the back of the Schottky electrode 20. In other words, it is important for conventional ones to make the area of the Schottky electrode greater. A conventional Schottky electrode also has a depletion layer greater than the electrode, which extends slightly around the electrode. To make the electrode area more efficiently and larger, the length of the boundary line between the electrode area and the exposure area becomes shorter, wherein its longest length equals the length of the outer periphery of the light receiving surface.

【Mode of Embodiment of the Invention】

The light receiving element of the present invention has, as shown in Fig. 1, a layer made of a first conductivity type GaN group semiconductor as a light receiving layer 1. With one side surface of the light receiving layer 1 as a light receiving surface 1a, at least a Schottky electrode 2 is formed on the light receiving surface 1a. The Schottky electrode is formed in such a way that, in the above state,

the total length of the boundary lines between the covered areas and the exposure areas (total length of a visible outline of Schottky electrode in the embodiment of Fig. 1(a)) is longer than the outer periphery of the light receiving surface. In Fig.1, L is the light to be detected.

The GaN group semiconductor as used in the present invention is a compound semiconductor defined by the formula $In_XGa_YAl_ZN$ ($0 \leqq X \leqq 1$, $0 \leqq Y \leqq 1$, $0 \leqq Z \leqq 1$, $X+Y+Z=1$).

The conductive type of the GaN group material used for the light receiving layer may be of a first conductivity type (i.e., p-type or n-type), but it is preferably of an n-type in view of the control of the impurity concentration and feasibility of electrode forming. The embodiment according to the present invention is explained in the following by all referring to the embodiment comprising an n-type light receiving layer.

The optimal components of the GaN group material used for the light receiving layer are determined by the end value of the longer wavelength within the wavelength range of the light to be the detected. For example, ① when a light in the blue region (near 480 nm) or of a wavelength range shorter than that is the target, InGaN is used, ② when an ultraviolet light in a short wavelength range of not more than 400 nm is the target, InGaN with less In component is used, and ③ when an ultraviolet light at not more than 365 nm is the sole target, GaN and AlGaN are used.

A Schottky electrode refers to an electrode having a potential barrier called a Schottky barrier due to the junction between a metal and a semiconductor. This electrode is formed from a metal characterized by an energy band diagram of the contact part between the metal and the semiconductor, and described in, for example, "Semiconductor Device", S. M. Sze (translated by Yasuo Nannichi et al.), Sangyo Tosho (first edition, 3rd printing) page 164. Since the height $q\phi$ of the Schottky barrier is the difference

between the work function ϕm of the metal and the electron affinity χ of the semiconductor, i.e., $q\phi = q(\phi m - \chi)$, and a material having a relatively large ϕm is desirable.

The material of the Schottky electrode is exemplified by Au, Pt, TiW and the like. These materials may be used in combination.

The shape of the electrode when the Schottky electrode is seen from the upper surface side needs to be, as stated in the foregoing explanation of the action, long enough to enable detection of the receipt of the light even solely with the light from the upper surface side of the electrode. This is explained in the following using a simple model.

Fig. 2 shows a shape of a Schottky electrode when the light receiving surface is a square of one side being a. The shape of the electrode is a comblike wiring pattern including three teeth of the comb. When the longitudinal and transverse sizes of the comb as a whole is 0.8a × 0.8a and the width of the strip conductors constituting the comb is 0.2a, the total length of the boundary lines between the electrode areas and the exposure areas is 5.6a, which is 1.4 times the length of the outer periphery of the light receiving surface 4a.

When the number of comb teeth is 8, as shown in Fig. 1, and the width of the strip conductors (electrode material) is 0.1a, the total length of the boundary lines is about 13a, which is about 3 times the length of the outer periphery of the light receiving surface.

When the shape of the Schottky electrode has a comblike wiring pattern, as shown in Fig. 1 and Fig. 2, the part corresponding to the comb teeth shows a stripe pattern with strip conductors arranged in parallel. Though subject to change depending on the size of the element and the arrange environment (intensity of light and the like), the width of the strip conductor corresponding to the comb teeth is preferably 0.1 μm - 2000 μm, and the width of the space between conductors is preferably 0.1 μm - 1000 μm.

In addition to the above-mentioned comblike shape, the shape of the Schottky electrode may be of a wiring pattern, which is an arbitrary combination of strip conductors. For example, a pattern formed by strip conductors meandering like a square wave, a grid-like cross pattern and the like are mentioned. The width of the strip conductors is the same as in the above-mentioned comblike shape, which is preferably 0.1 μm - 2000 μm. It may be a pattern including an opening having an optional shape as an exposure area, besides the above-mentioned pattern. The greater the number of openings, the greater the total length of the boundary lines between electrode areas and exposure areas.

The light receiving element according to the present invention is preferably constituted as a laminate comprising a GaN group material layer which is crystal grown on a crystal substrate, as in the case of a typical semiconductor light emitting element. In this case, the light receiving layer is located as the uppermost layer of the laminate. The structure of this laminate and the positional relationship between the Schottky electrode and ohmic electrode is exemplarily shown in Fig. 3.

In the embodiment of Fig. 3(a), a light receiving layer 1 comprising an n-type GaN group crystal is crystal grown on a crystal substrate B1 via a buffer layer B2, wherein an ohmic electrode and the Schottky electrode are formed on the same light receiving surface.

In the embodiment of Fig. 3(b), an n-type GaN group crystal layer 4 to form an ohmic electrode is formed separately from the light receiving layer. Such embodiment is preferable, because a carrier concentration suitable for each of the Schottky electrode and ohmic electrode can be independently easily set. While the ohmic electrode is formed on the upper surface of a layer 4, it may be formed to surround the complete circumference of the light receiving layer, as a planar arrangement pattern.

In the embodiment of Fig. 3(c), the crystal substrate is made from a conductive material and the ohmic electrode is formed on the crystal substrate.

An ohmic electrode refers to one wherein metal-semiconductor contact does not show rectification properties (irrespective of the direction of the voltage to be applied), and contact resistance can be almost ignored (see, for example, "Semiconductor Device", S. M. Sze (translated by Yasuo Nannichi et al.), Sangyo Tosho (first edition, 3rd printing, pages 163, 174)). The contact between a semiconductor doped at a high concentration and a metal markedly narrows the width of the depletion layer to be formed, which in turn facilitates the flow of a tunnel current, easily making the electrode ohmic.

The material of the ohmic electrode is exemplified by Al/Ti, Au/Ti, Ti and the like. These materials may be used in combination.

In addition, since a voltage is applied to make backward bias applied to the Schottky electrode side, the presence of Schottky barrier on the ohmic electrode side does not pose a serious problem. This means that, even if the both electrodes are formed with a Schottky electrode, when a backward bias voltage is applied to the electrode on the light receiving surface, the forward bias is applied to the other electrode, as a result of which it functions like an ohmic electrode.

The crystal substrate may be any as long as a GaN group semiconductor can be crystal grown, and is exemplified by sapphire, quartz, SiC etc., and a GaN group crystal.

When a crystal substrate is an insulator, a sapphire substrate (C face, A face), particularly sapphire substrate (C face), is preferable. When a crystal substrate requires conductivity, a 6H-SiC substrate and a GaN group crystal are preferable. As shown in Fig. 3(a), moreover, a laminate comprising a buffer layer of ZnO, MgO, AlN and the like,

which is formed on the surface of a sapphire crystal substrate and the like, to alleviate the difference in the lattice constant with GaN group crystal, and also the coefficient of thermal expansion, may be regarded a substrate, and a thin film of a GaN group crystal may be further formed thereon.

The light to be received by the light receiving element of the present invention varies depending on the GaN group material used for the light receiving layer. However, when a light having a short wavelength from blue to ultraviolet light, X rays is the target, the utility of the present invention becomes noticeable. In particular, ultraviolet light having a shorter wavelength, such as the light having a wavelength of 248 nm, which is emitted by a KrF excimer laser device, the light having a wavelength of 193 nm, which is emitted by an ArF excimer laser device and the like, have an intense energy, which causes many problems. By the use of a GaN group semiconductor to receive such ultraviolet light having a shorter wavelength, a superior light receiving element having an improved resistance to ultraviolet light can be obtained.

【Examples】

Example 1

In this Example, the Schottky electrode to be formed on the light receiving surface had a comblike wiring pattern, and the Schottky electrode and an ohmic electrode were both formed on the light receiving surface.

As shown in Fig. 3(a), an n-type AlGaN layer (light receiving layer) 1 was grown on a sapphire substrate (C face) B1 via a GaN buffer layer B2. The AlGaN layer had a component ratio that made the band gap about 3.67 eV, a thickness of 3 μm, a light receiving surface having a 5 mm × 5 mm square outer periphery, and a carrier concentration of 1×10^{17} cm^{-3}.

The Schottky electrode having a comblike pattern was formed in a 5 mm × 4840 μm square area in the square light

receiving surface, and a square ohmic electrode was formed in the remaining area, the two facing each other.

The Schottky electrode was made from Au and had a thickness of 500 nm and a comblike pattern having 500 teeth. The total length of the boundary lines between the electrode areas and exposure areas was about 230 times the length of the outer periphery of the light receiving surface.

The ohmic electrode was formed on the light receiving surface in the order of Ti layer and Al layer.

Applying a 5V backward bias between both electrodes, a light having various wavelengths was applied from the direction perpendicular to the light receiving surface to examine the properties of the light receiving. As a result, the presence of sensitivity was acknowledged with regard to the ultraviolet light at not more than about 340 nm. With regard to the range of wavelength at not more than 340 nm, light absorption properties of AlGaN that pose problems in the conventional cases where the light enters from the substrate side, conversely contributed to the light receiving sensitivity in the present invention, making the properties flat. With regard to the range of wavelength longer than 340 nm, because the light was not absorbed and the temperature of the element did not rise very much, no sensitivity was found.

Example 2

In this Example, the Schottky electrode had a comblike wiring pattern, and an ohmic electrode was formed on the crystal substrate comprising an n-type semiconductor.

As shown in Fig. 3(c), an n-type InGaN layer (light receiving layer) 1 was grown on the n-type GaN crystal substrate B1. The InGaN layer had a component ratio that made the band gap about 2.93 eV, a thickness of 5 μm, a light receiving surface having a 1 mm × 1 mm square outer periphery and a carrier concentration of 1×10^{18} cm^{-3}.

The Schottky electrode was made from Au and had a thickness of 20 nm and a comblike pattern having 200 teeth.

The total length of the boundary lines between the electrode areas and exposure areas was about 86 times the length of the outer periphery of the light receiving surface.

The ohmic electrode was formed on the back of the n-type GaN crystal substrate B1 in the order of Ti layer and Al layer.

Applying a 3V backward bias between both electrodes, the properties of the light receiving were examined as in Example 1. As a result, the presence of sensitivity was acknowledged with regard to the ultraviolet light at not more than about 425 nm. With regard to the wavelength range of not more than 425 nm, the properties were flat, as in Example 1. With regard to the range at a wavelength longer than 425 nm, no sensitivity was found.

【Effect of the Invention】

As explained in the foregoing, the light receiving element of the present invention comprises a GaN group material, which results in superior resistance to ultraviolet light. While it is a Schottky barrier type PD and has an opaque electrode, its structure permits receipt of the light from the upper surface side of the Schottky electrode. This has a consequence that the light to be received does not pass a layer made from a GaN group material, but can enter the depletion layer directly even from the electrode side. By this constitution, the element has superior sensitivity even to the light having a blue to ultraviolet range wavelength. In particular, a shorter wavelength does not cause decreased sensitivity.

【Brief Description of the Drawings】

Fig. 1 shows one embodiment of the light receiving element of the present invention, wherein Fig. 1(a) shows the light receiving surface and Fig. 1(b) is an end view partially showing the section of Fig. 1(a) along the line X-X. Hatching is applied to identify electrodes.

Fig. 2 shows the relationship between a light receiving

surface and the shape of a Schottky electrode in the light receiving element of the present invention.

Fig. 3 shows an example of the structure of the light receiving element of the present invention, which is an end view of the light receiving element of Fig. 1(a) cut along the line similar to X-X. Hatching is applied to identify electrodes.

Fig. 4 shows comparison of the present invention and a conventional embodiment with regard to the relationship between the depletion layer of a Schottky barrier and incident light.

【Explanation of the Symbols】

1 : light receiving layer

1a: light receiving surface

2 : Schottky electrode

【Document】 Abstract

【Summary】

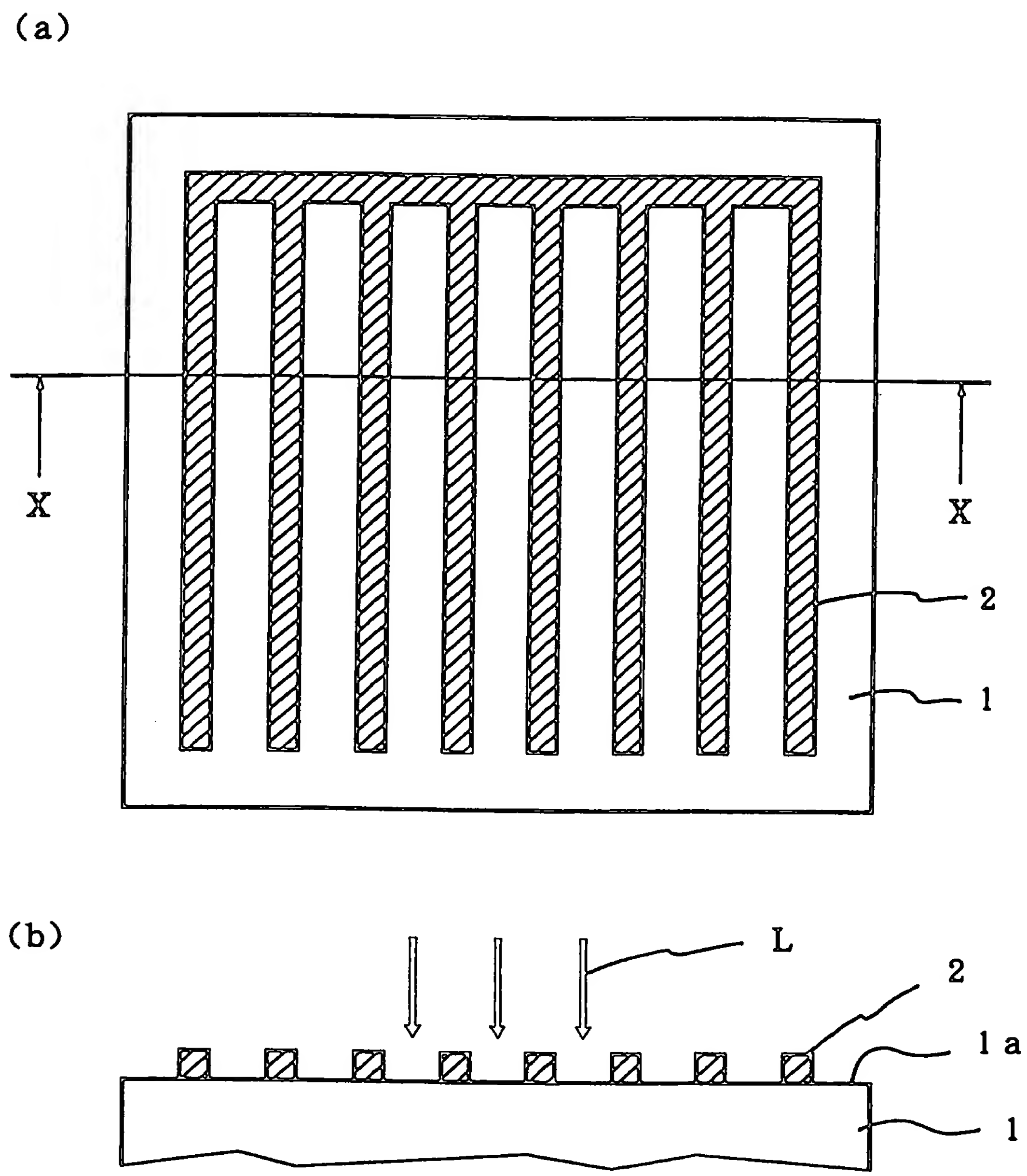
【Problem】 Provision of a Schottky barrier type semiconductor light receiving element having, besides the superior resistance also to a light having a wavelength in the ultraviolet range, superior sensitivity as compared to conventional ones, based on a new constitution.

【Solving Means】 A Schottky barrier type photodiode comprising a layer of n-type or p-type GaN group semiconductor as a light receiving layer 1, and at least a Schottky electrode 2 formed on a light receiving surface 1a, which is one side surface of the light receiving layer 1, wherein the total length of the boundary lines between the area covered with the Schottky electrode and exposure areas of the light receiving surface 1a is longer than the outer periphery of the light receiving surface, thereby enabling receipt of the light L irradiated from the upper surface side of the Schottky electrode.

【Main Drawing】 Fig. 1

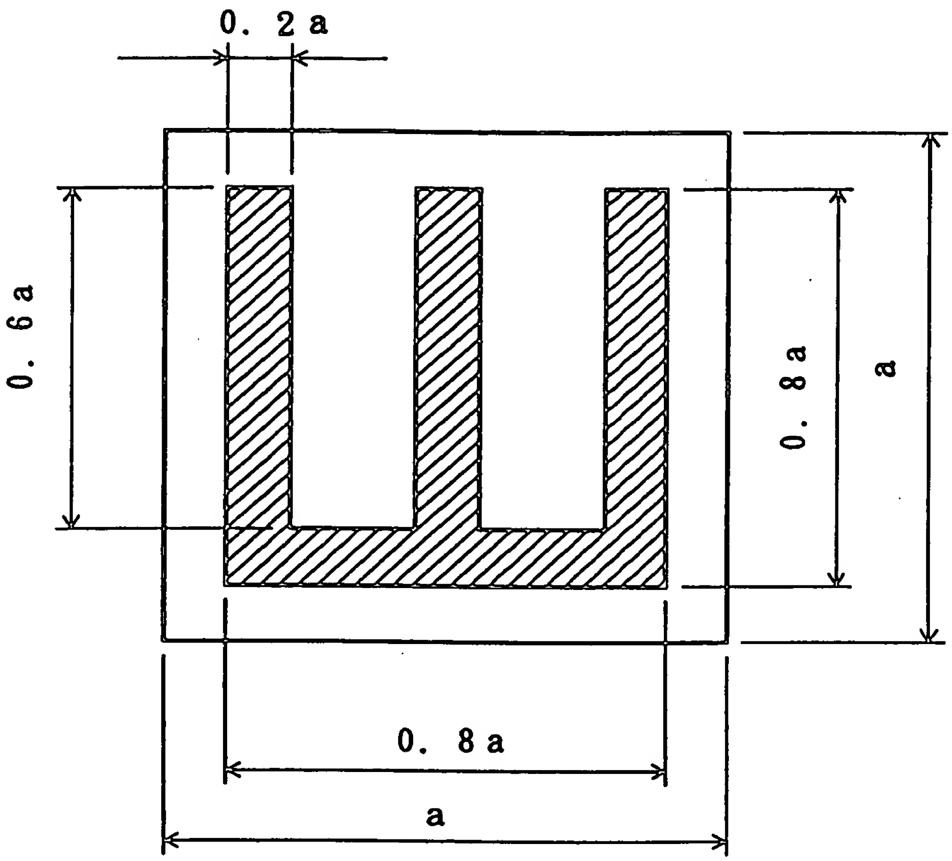
【Document】 DRAWINGS

【Fig. 1】

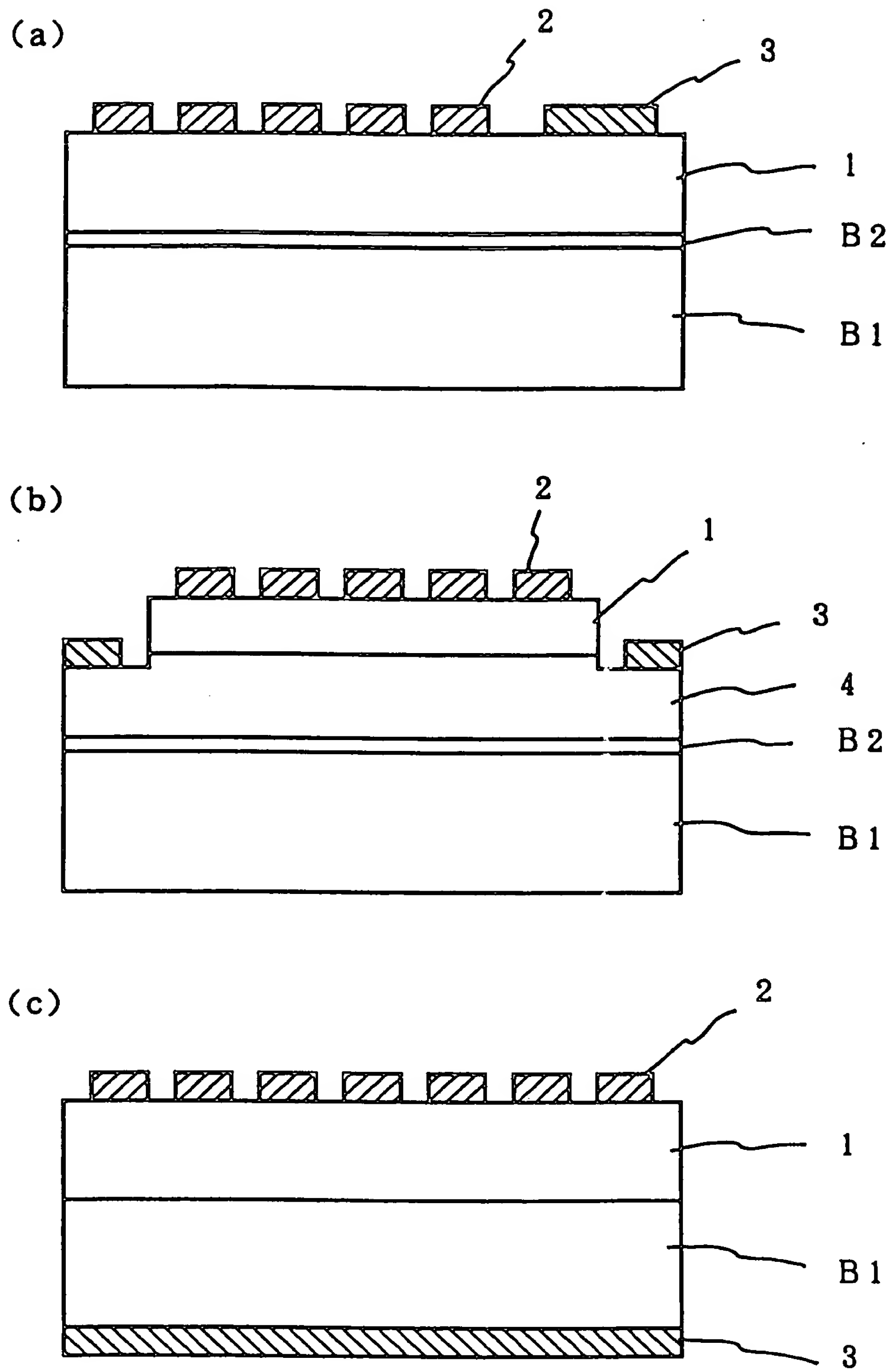


1 : light receiving layer
1a: light receiving surface
2 : Schottky electrode

【Fig. 2】

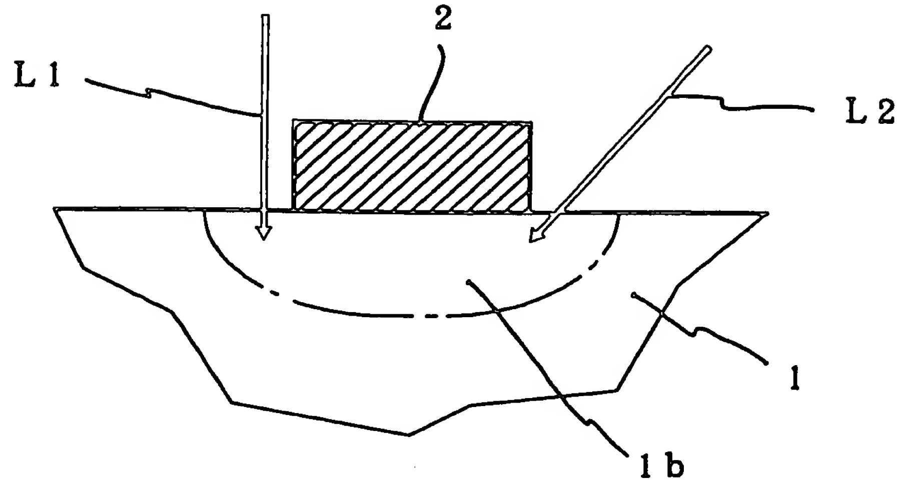


【Fig. 3】



【Fig. 4】

(a)



(b)